A 125 GeV Higgs Boson and Goldilocks Cosmology

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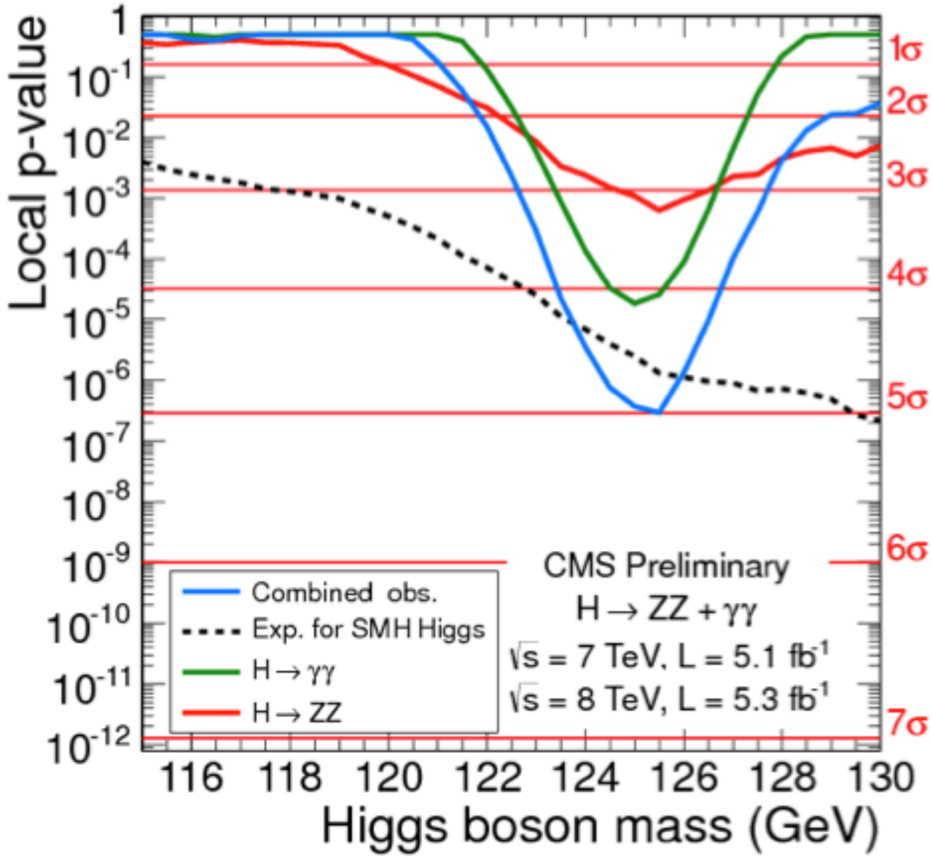
Santa Fe 2012

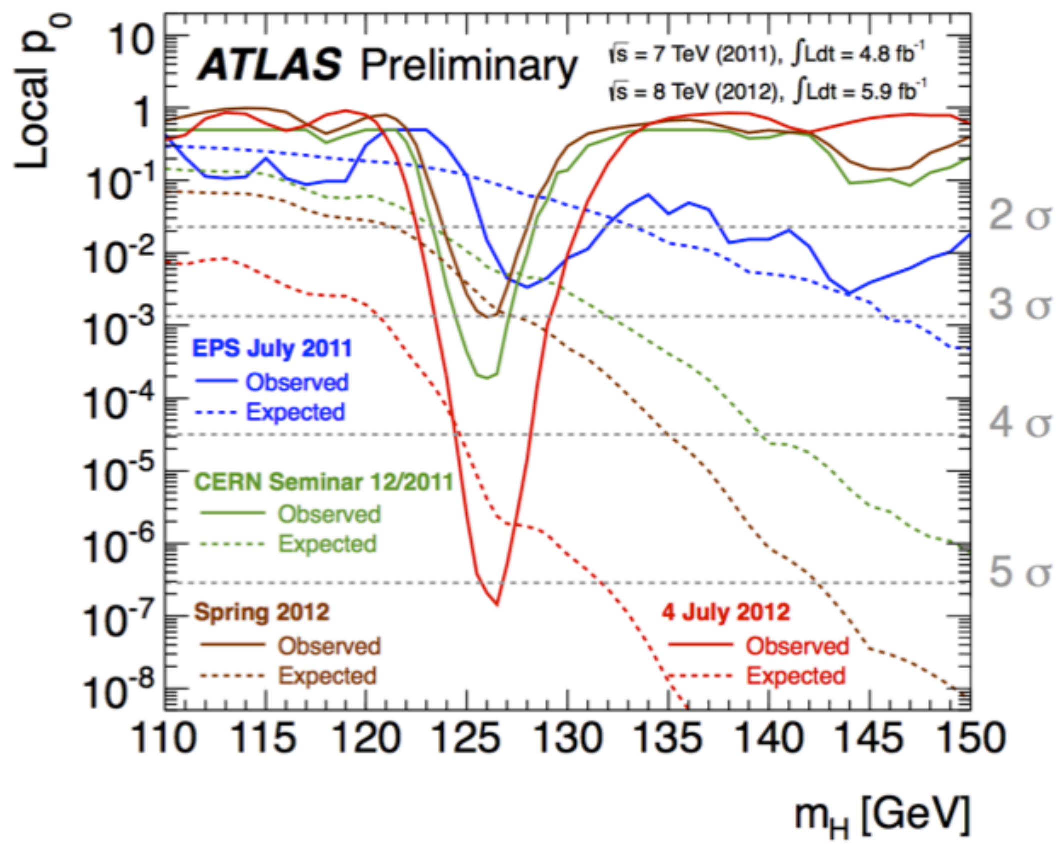
Jonathan Feng, Ze'ev Surujon, and HBY arXiv:1205.6480 [hep-ph]

Higgs Boson Discovery

CMS

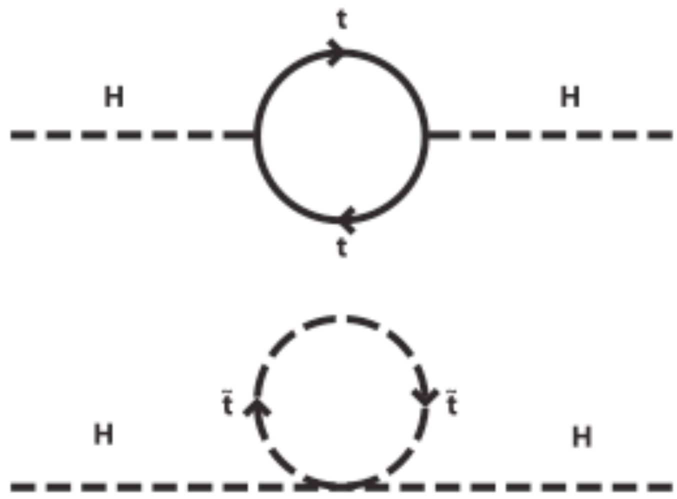


ATLAS



Higgs Discovery and SUSY

- At first glance



Great!

Higgs Discovery and SUSY

- Closer view

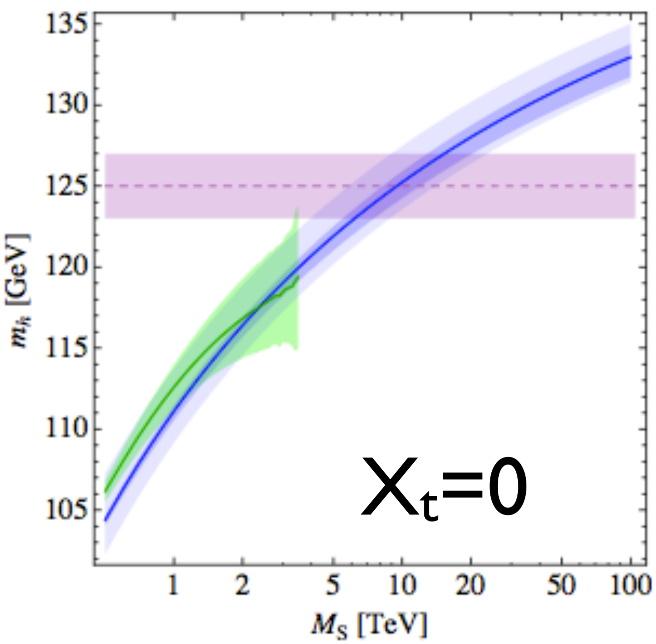
Tree-level $m_h^2(\text{tree}) = M_Z^2 \cos^2 2\beta$

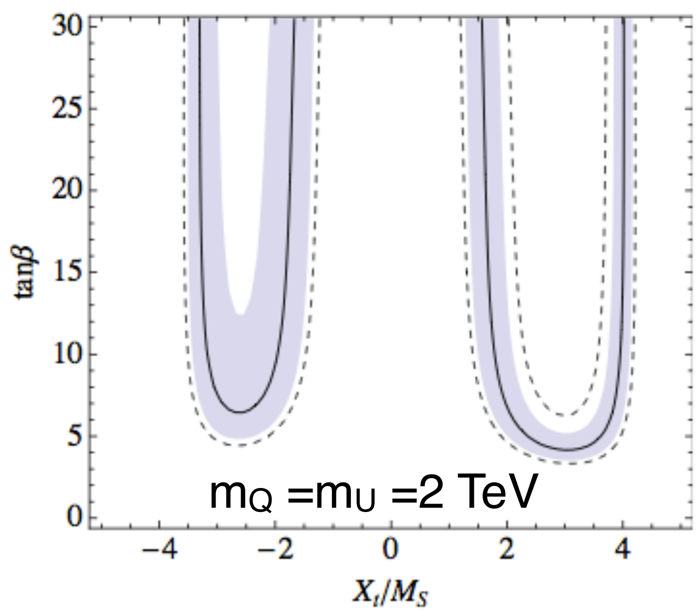
Large loop-level corrections from heavy stops

$$\Delta m_h^2(\text{1-loop}) = \frac{3m_t^4}{2\pi^2 v^2}\left[\log\left(\frac{M_S^2}{m_t^2}\right) + \frac{X_t^2}{M_S^2}\left(1 - \frac{X_t^2}{12M_S^2}\right)\right]$$

$$M_S \equiv \sqrt{m_{\tilde{t}_1} m_{\tilde{t}_2}}$$

$$X_t \equiv A_t - \mu \cot\beta$$





Reconsider many SUSY models

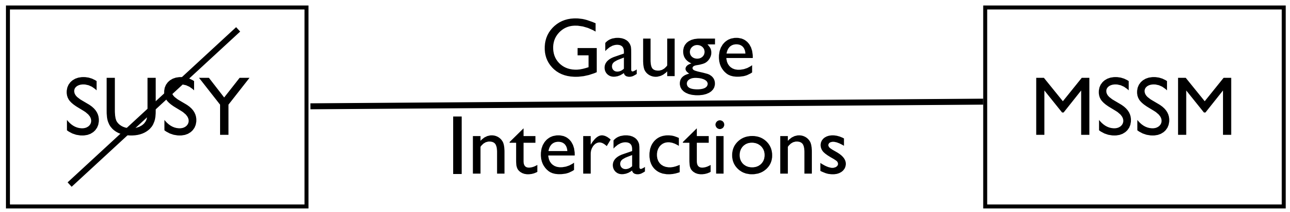
Large M_s

Large X_t

Beyond MSSM

Draper, Meade, Reece, Shih (2011)

Reconsider GMSB



- Gauge-mediated SUSY breaking
  - a beautiful framework that suppresses unwanted flavor violation
  - soft masses are calculable
- Generically, a 125 GeV Higgs is very challenging in GMSB: Vanishing A terms $\Rightarrow$ M_s (Not natural)
- Other solutions: see Shih and Craig`s talk

CP Violation

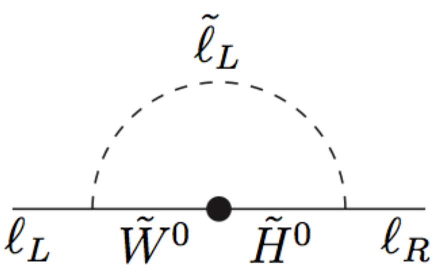
But GMSB has other difficulties

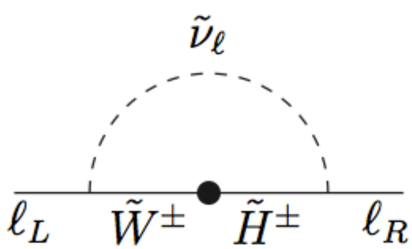
- In general, GMSB suppresses FCNCs and flavor-violating CP phases but not flavor-conserving CP phases

$$\mathrm{Arg}(A^* M_a) \qquad\qquad \mathrm{Arg}(\mu M_a B_\mu^*)$$

Vanishing — Related to μ/B_μ problem

- These CP-violating phases may lead to sizable electric dipole moments for the electron and neutron





...

$$d_e < 1.05 \times 10^{-27}\ e\ \mathrm{cm}$$

Hudson et al. (2011)

$$d_n < 2.9 \times 10^{-26}\ e\ \mathrm{cm}$$

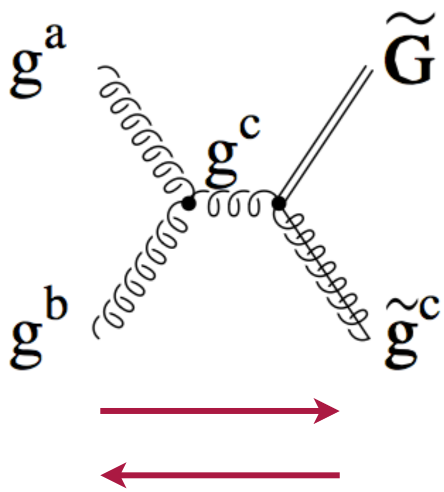
Baker et al. (2006)

Dark Matter Problem

- WIMP miracle $\Omega h^2 \simeq 0.11 \left(\frac{1\mathrm{pb}}{\langle \sigma v \rangle} \right)$

No miracle in GMSB: Neutralinos decay to gravitinos

- Thermally-produced light gravitino



$$\Omega_{\tilde{G}} h^2 \simeq 0.1 \left[\frac{m_{\tilde{G}}}{100\ \mathrm{eV}} \right] \left[\frac{106.75}{g_{*S,f}} \right]$$

Hot DM!

Lyman-α $\Rightarrow$ $m_{\tilde{G}} > 2$ keV

Excluded

Our Approach

Let`s allow the little hierarchy and ask the following question.

If we increase the stop mass, can we solve the Higgs mass and dark matter problems, and suppress EDMs all together simultaneously?

A Simple Example

- Assume μ, B_μ are generated such that v=174 GeV, and we trade them for $\tan\beta = v_u/v_d$ and v
- The resulting free parameters are $\tan\beta$ and sign(μ)

M_m, $\Lambda = F/M_m$, N_m

Sfermion

$$m^2_{\tilde{f}}(M_\mathrm{m}) = 2N_\mathrm{m}\,\Lambda^2 \sum_{i=1}^{3} C_i^f \left[\frac{g_i^2(M_\mathrm{m})}{16\pi^2}\right]^2$$

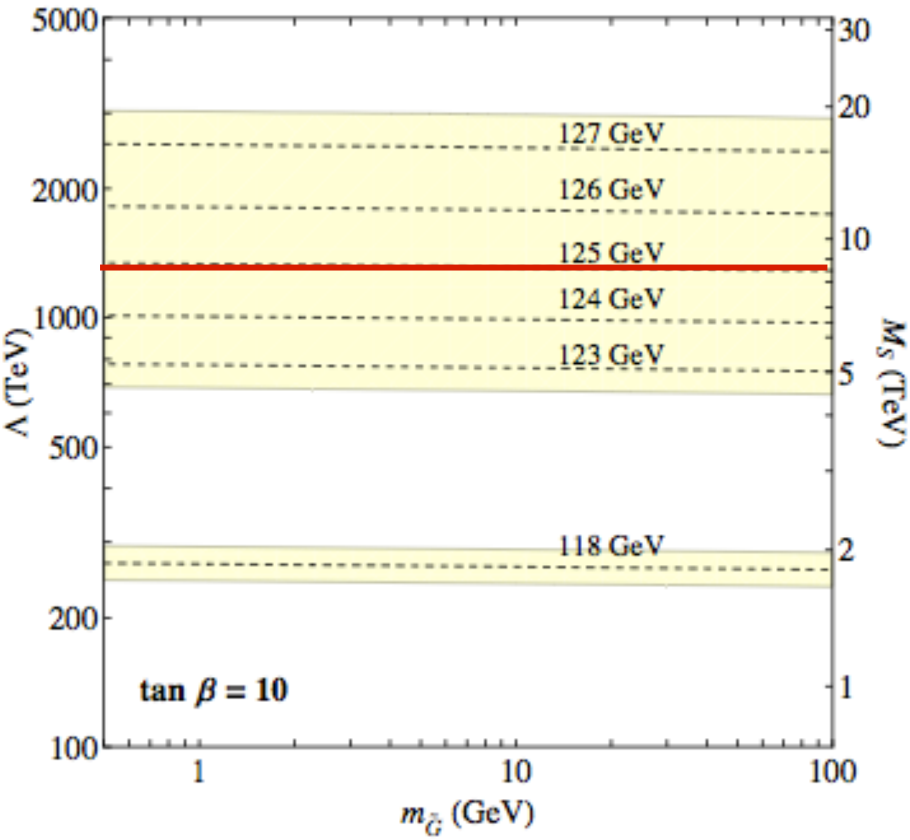
Gaugino

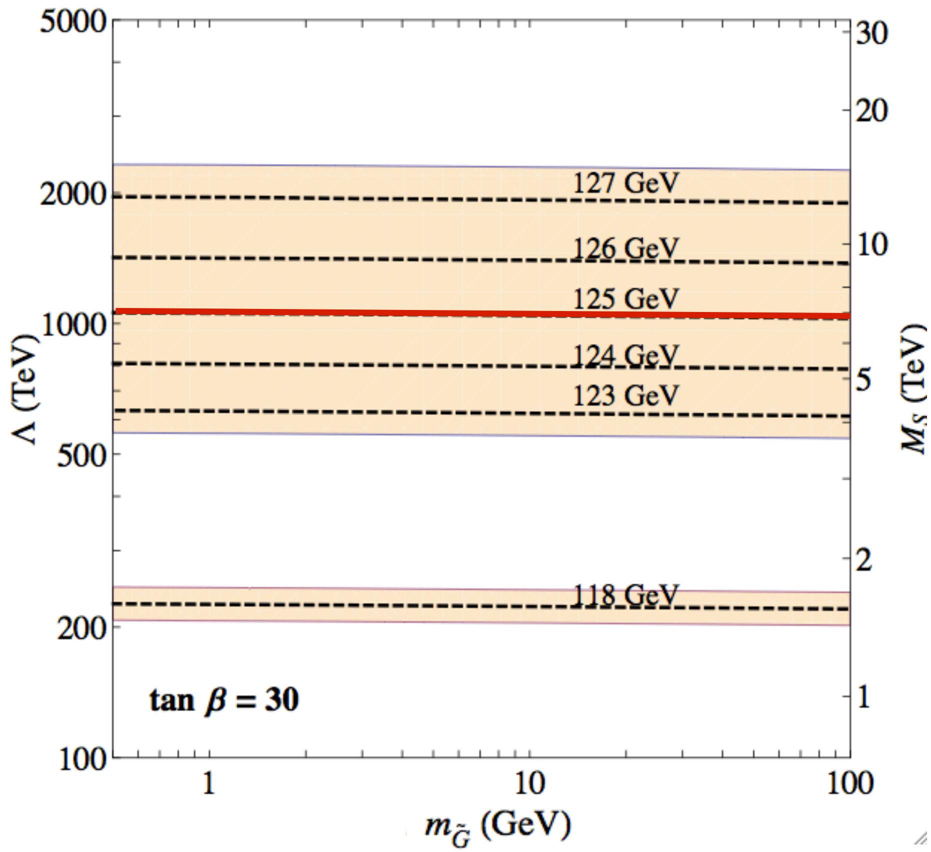
$$M_i(M_\mathrm{m}) = N_\mathrm{m}\,\Lambda\, c_i \frac{g_i^2(M_\mathrm{m})}{16\pi^2}$$

Gravitino

$$m_{\tilde{G}} = \frac{F}{\sqrt{3}M_*} = \frac{M_\mathrm{m}\Lambda}{\sqrt{3}M_*}$$

A 125GeV Higgs Boson





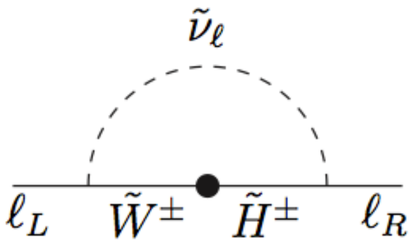
To get a ~125 GeV Higgs boson, Ms~7 TeV-9TeV

Electric Dipole Moments

$$\theta_{\rm CP} = {\rm Arg}(\mu M_a B_\mu^*)$$

- Need to know how to generate μ/B_μ

- A phenomenological approach: Assume θ_{CP} is not zero, and check its contributions to EDMs



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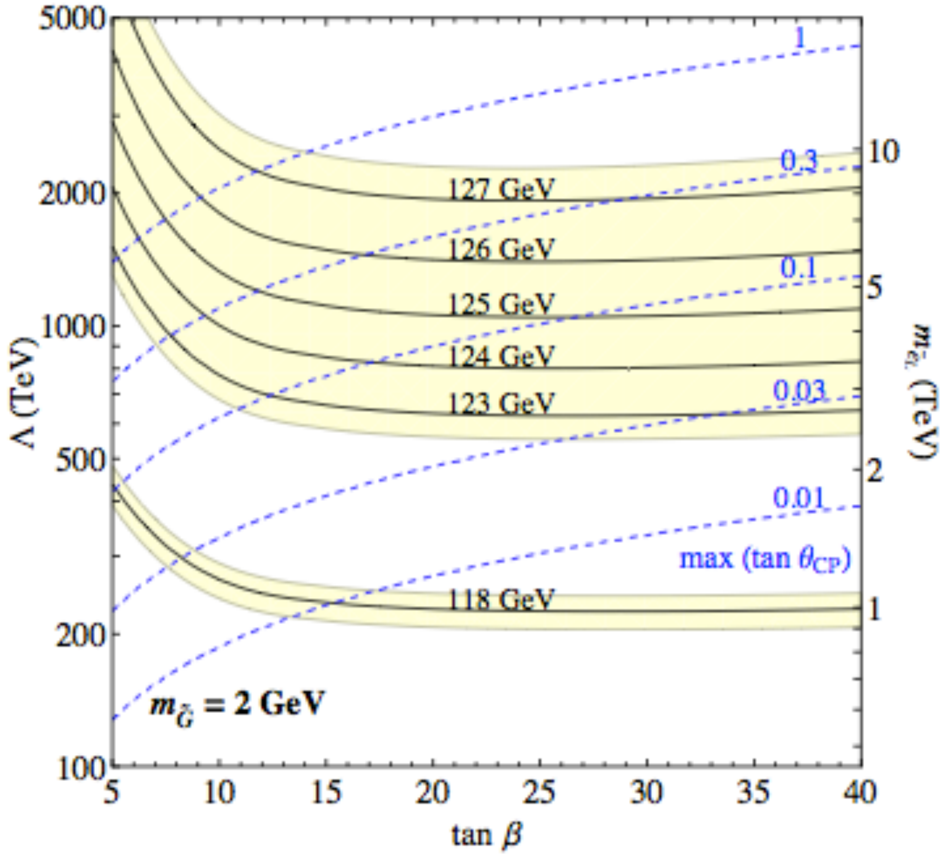
$$d_f = \frac{1}{2} e\, m_f\, g_2^2\, |M_2\, \mu|\, \tan\beta\, \sin\theta_{\rm CP}\, K_C\left(m_{\tilde{f}_L}^2, |\mu|^2, |M_2|^2\right)$$



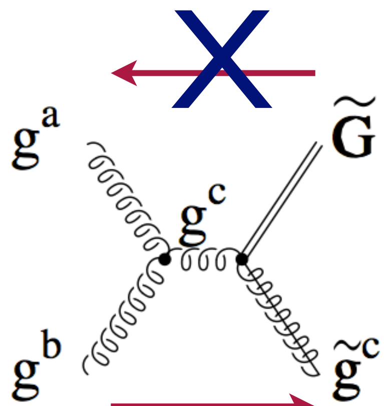
$$d_e < 1.05 \times 10^{-27}\ e\ {\rm cm}$$

Hudson et al. (2011)

The Higgs and EDM constraints point to the same parameter space

Dark Matter

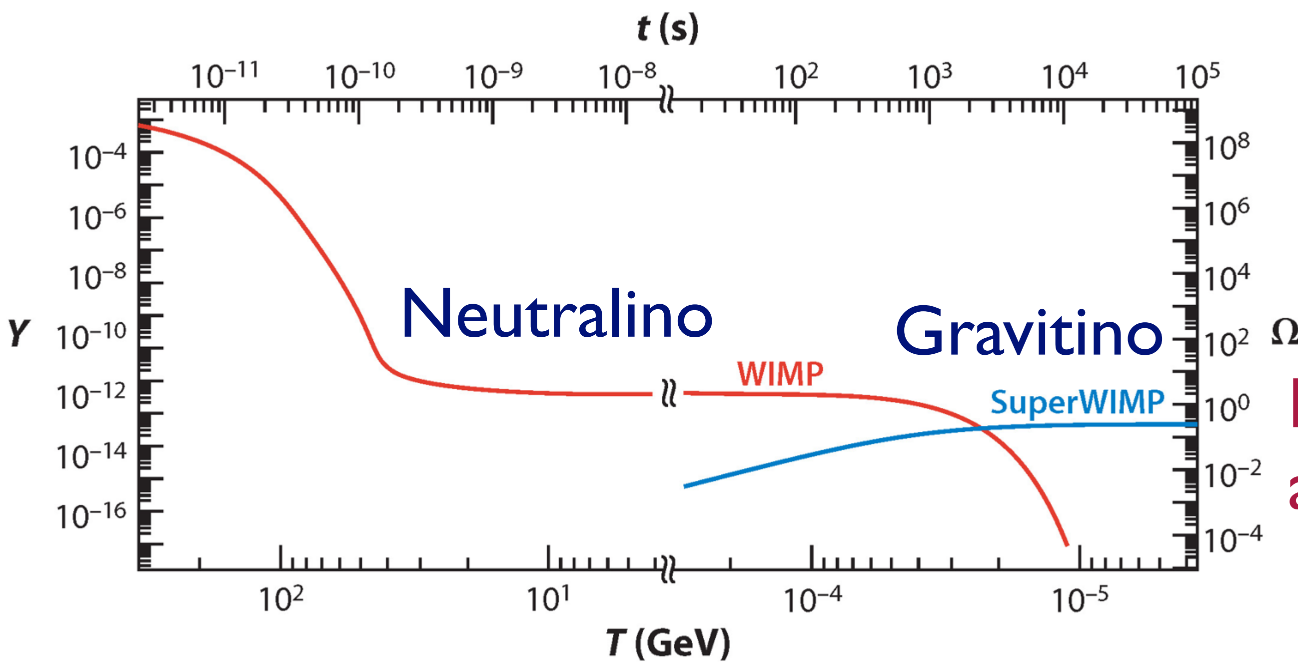
- Produced after reheating



$$\Omega_{\tilde{G}} h^2 \approx 0.13 \left(\frac{T_R}{10^6 \text{ GeV}}\right)\left(\frac{1 \text{ GeV}}{m_{\tilde{G}}}\right)\left(\frac{m_{\tilde{g}}}{7 \text{ TeV}}\right)^2$$

Adjust T_R, nothing to do with the WIMP miracle, rely on other physics

- Produced from the WIMP decay

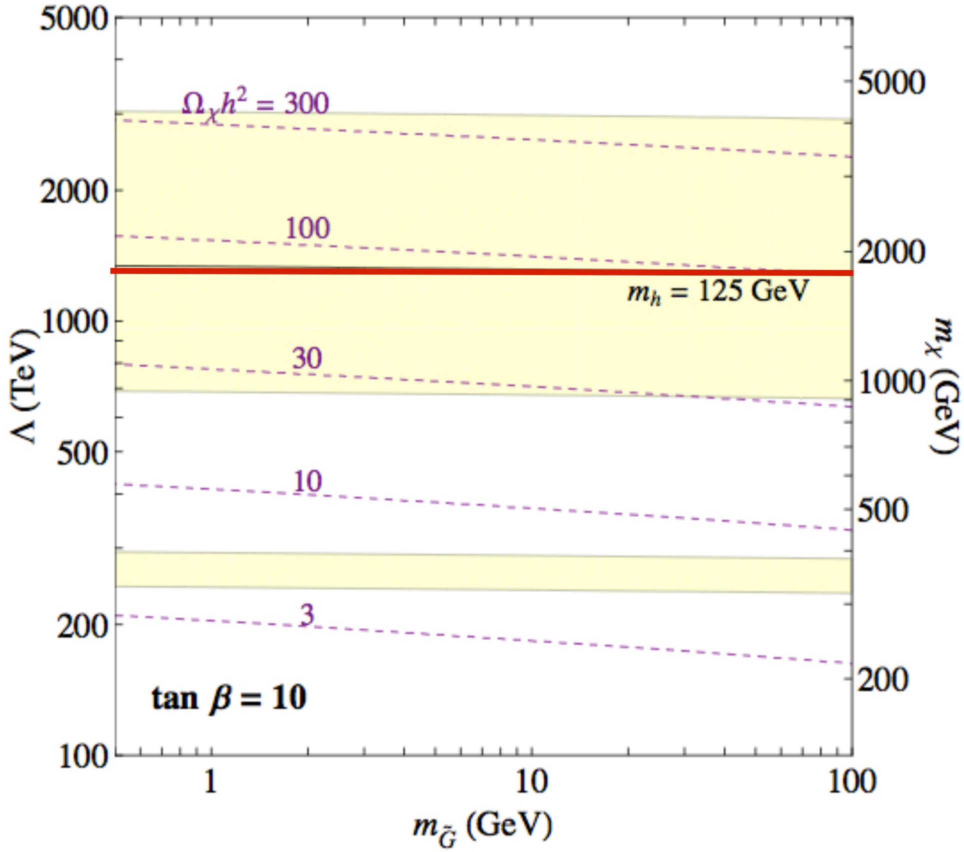


$$\Omega_{\tilde{G}} h^2 = \frac{m_{\tilde{G}}}{m_\chi} \Omega_\chi h^2$$

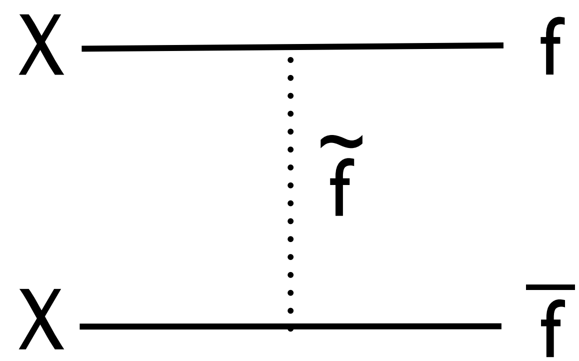
Keep the WIMP miracle as much as possible

Feng, Rajaraman, Takayama (2003)

Neutralino Abundance



Bino is the lightest SUSY partner of SM particles

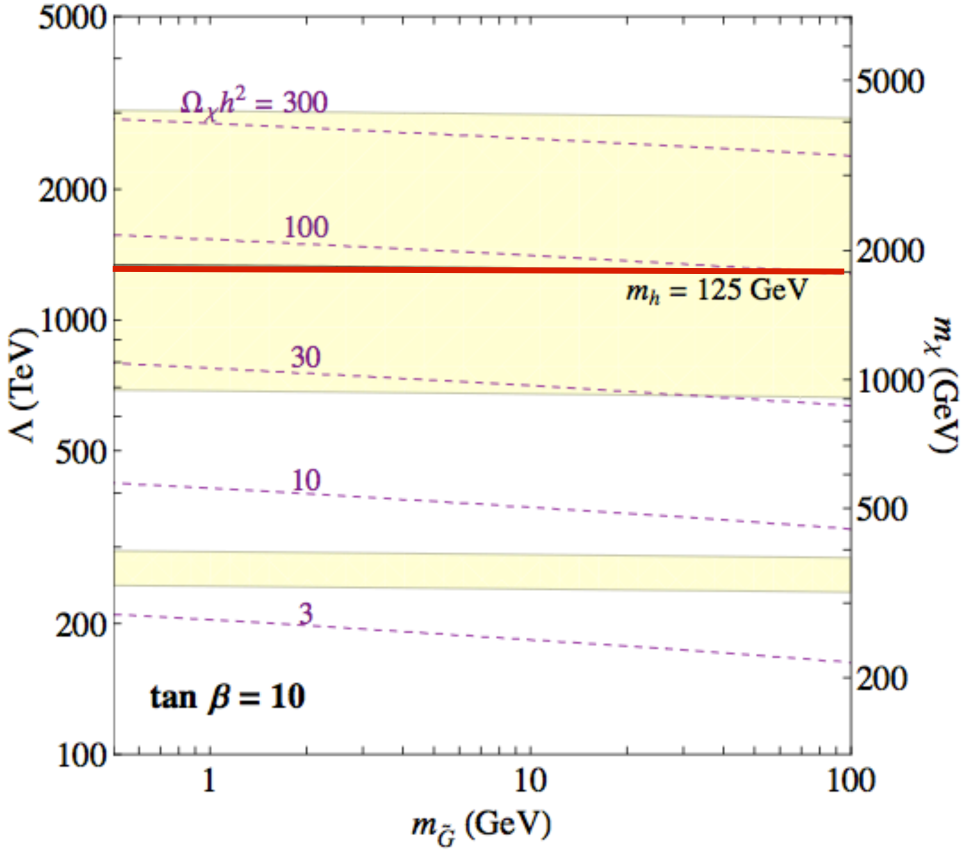


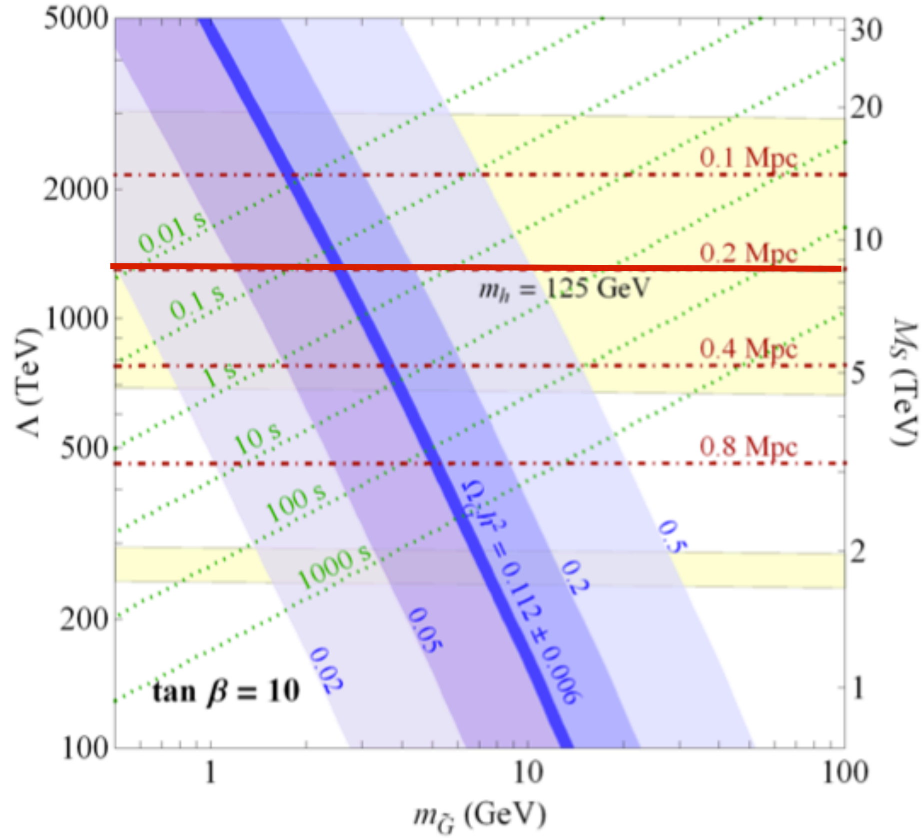
Annihilation to fermions is dominated by the p-wave process

$$\sigma v \propto v^2$$

Fortunately, neutralinos decay to gravitinos

Gravitino Abundance





$$\Omega_{\tilde{G}} h^2 = \frac{m_{\tilde{G}}}{m_\chi} \Omega_\chi h^2$$

The ~GeV gravitino is light enough to avoid the flavor problem, and heavy enough to be all dark matter

Goldilocks Cosmology

Several constraints:

- Dark matter density

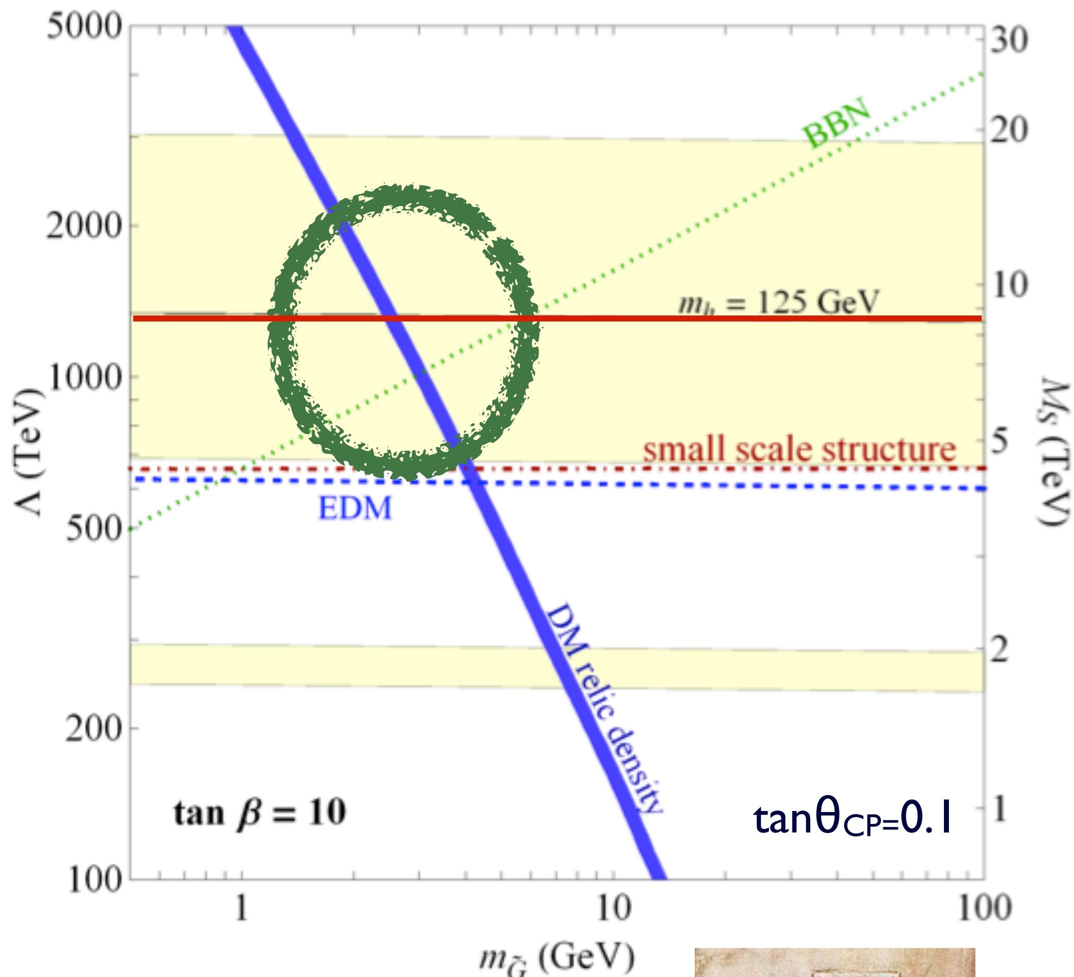
$$\Omega_{\tilde{G}} h^2 = \frac{m_{\tilde{G}}}{m_\chi} \Omega_\chi h^2$$

- BBN (~1s)

$$\tau_\chi \simeq \frac{48\pi m_{\tilde{G}}^2 M_*^2}{m_\chi^5} \simeq 0.02\ \mathrm{sec} \left(\frac{m_{\tilde{G}}}{1\ \mathrm{GeV}}\right)^2 \left(\frac{2\ \mathrm{TeV}}{m_\chi}\right)$$

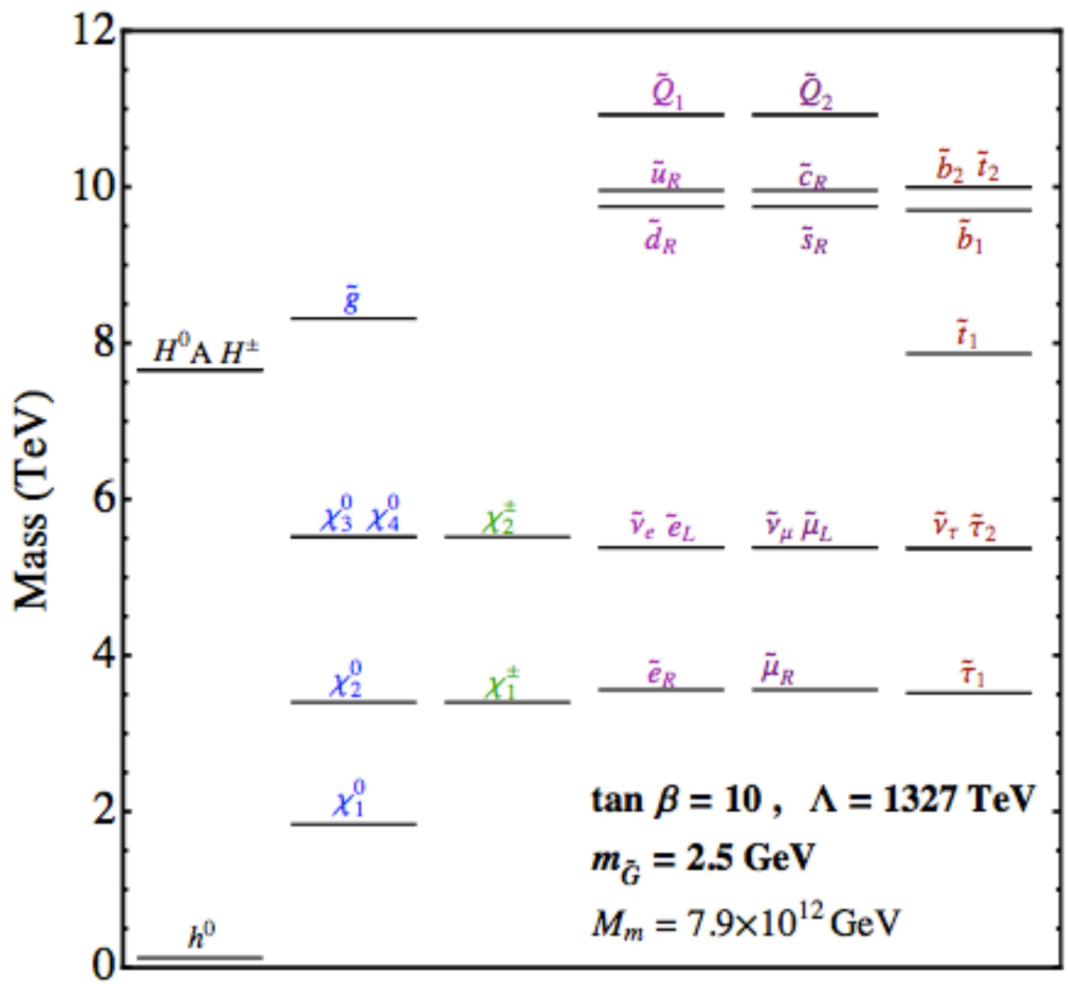
- Cold enough (λ_{FS} < 0.5 Mpc)

$$\lambda_{\rm FS} \simeq 1.0\ \mathrm{Mpc} \left[\frac{u_\tau^2 \tau}{10^6 \mathrm{s}}\right]^{1/2} \left[1 - 0.07 \ln\left(\frac{u_\tau^2 \tau}{10^6\ \mathrm{s}}\right)\right]$$



All constraints are satisfied in the same region

Superpartner Mass Spectra



Not easy at the LHC

Summary

- The discovery of the Higgs boson motivates restudies of models beyond the SM
- We consider a simple high-scale GMSB model
  - Minimal field content; standard cosmology
  - Non-thermal dark matter from late decays
- Implications
  - A 125 GeV SM-like Higgs boson; No superpartners at the LHC
  - The search for EDMs is promising
  - Warm dark matter $\lambda_{FS} \sim 0.1 - 0.5$ Mpc (may provide a solution to the small-scale structure problem)